

plane mirror is set at right angles to the optic axis in the principal focus of a cylindrical lens. Between the lens and the eye a plate of unsilvered glass is placed at such an angle as to reflect the rays from some distant object through the lens on to the mirror, whence they are reflected once more through the lens into the eye. The unsilvered reflection is not necessary if the eye is held at some considerable distance from the lens. In such an arrangement the image is not enantiomorphic, the effect of the cylindrical lens-system being neutralised by that of the mirror, but the image rotates when the lens is rotated exactly as in an ordinary cylindrical telescope, and the plane of polarisation is not affected by the rotation.

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“On the Effect of a Magnetic Field on the Rate of Subsidence of Torsional Oscillations in Wires of Nickel and Iron, and the Changes Produced by Drawing and Annealing.” By Professor ANDREW GRAY, F.R.S., and ALEXANDER WOOD, B.Sc. Received March 12,—Read March 17, 1904.

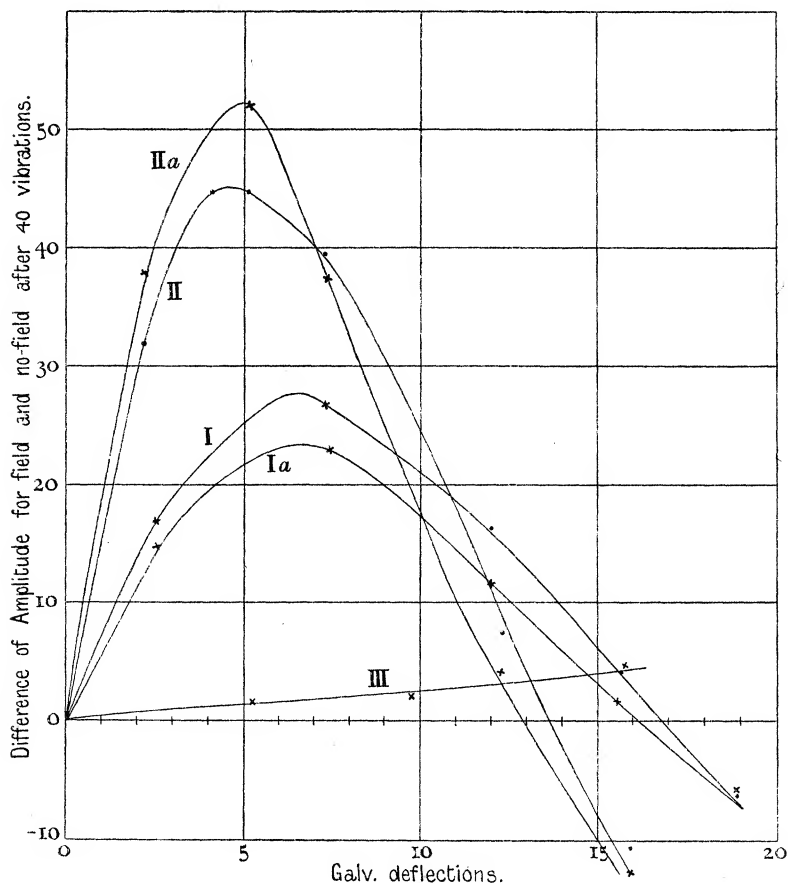
On May 15th, 1902, we communicated to the Royal Society a paper entitled “On the Effect of a Longitudinal Magnetic Field on the Internal Viscosity of Nickel and Iron, as shown by Change of the Rate of Subsidence of Torsional Oscillations.” We described in that paper the results of experiments on the rates of subsidence of torsional oscillations in nickel and iron wires in fields of different strengths, and showed that the effect of the field, or, more properly, of the magnetisation of the wire, is to increase the rate of subsidence in nickel and to diminish it in iron. In nickel, it was pointed out, this effect rose to a maximum at a certain field, from 100—180 C.G.S., according to the initial amplitude, and thereafter diminished as the field was increased; while in iron the effect was in the main all produced at a field of about 160 C.G.S. or rather less, and increased only slightly with further increase of field intensity.

The experiments described in the present paper are referred to at the end of the former one as in progress, and some account of their results is given; and we propose now to describe them a little more in detail.

*Experiments on the Effect of Drawing Down and of Annealing a Nickel Wire.*—A piece of the nickel wire formerly experimented on was tested for subsidence in the manner already described, and then drawn down, by being passed through a draw plate, from the diameter 1.4 mm. to 0.775 mm. The results are illustrated by fig. 1. Take first curve I of that figure. It has for ordinates the differences between

the amplitudes at a given stage in the course of the subsidence with various fields, and the amplitudes at the same stage in the subsidence with zero field. The stage chosen was in each case the instant after the completion of the fortieth vibration after the attainment of the initial amplitude indicated on the curve. The abscissæ are galvano-

FIG. 1.



meter deflections and are proportional to the fields: each unit of deflection means a field of 15.54 C.G.S. units.

Curve I shows the effects of the various fields on the wire as it was received from the makers. The wire was then hardened by being drawn down as described; and it was then found that no effect of magnetisation on subsidence was perceptible.

The nickel wire was next annealed by heating it to a bright red heat

and then plunging it into cold water; when it was found to be softer than it was originally. For the original wire, for example, the modulus of rigidity was  $7.97 \times 10$  C.G.S., for the wire as drawn down it was  $8.06 \times 10$  C.G.S., and for the annealed wire it was  $7.81 \times 10$  C.G.S. Curve II is the curve for the annealed wire corresponding to curve I, that is, showing the differences after forty oscillations of the amplitudes of oscillation of the wire under the various fields and the amplitude with zero field. The latter amplitude it is to be remembered was the greater.

After annealing and re-drawing had been performed in succession, the wire gave curve III, and its rigidity modulus was  $8.318 \times 10$  C.G.S.

These three curves make it clear that the effect of the magnetic field on the internal viscosity of a nickel wire depends very largely on the hardness of the metal, as, of course, we should expect.

The progressive modification of the groups of molecular magnets by the magnetic field is opposed by the greater resistance introduced by the hardening, and the changes due to the field are not produced. In the annealed condition the wire has its groups much more at liberty to take up a new arrangement, and this is shown also, of course, by the smaller magnetic susceptibility in the hardened condition.

Curves  $I_a$ ,  $II_a$ , give the results as in I and II, but after twenty oscillations. It will be observed that while  $II_a$  is above II up to and beyond the field of maximum difference of amplitude, and is then below II, curve  $I_a$  is below II throughout its entire course.

*Effect of Drawing Down on the Iron Wire.*—This is shown in fig. 2, in which the ordinates and abscissæ represent the same quantities as do the ordinates and abscissæ of the curves in fig. 1, after twenty oscillations in each case. The amplitude for iron, it is to be remembered, is greater with field than with no field. The steep rise of curve I, and the horizontality of the remaining part, show the fact noted in the former paper, that the effect of the magnetisation in iron is attained with low fields, and that higher then produce little further effect.

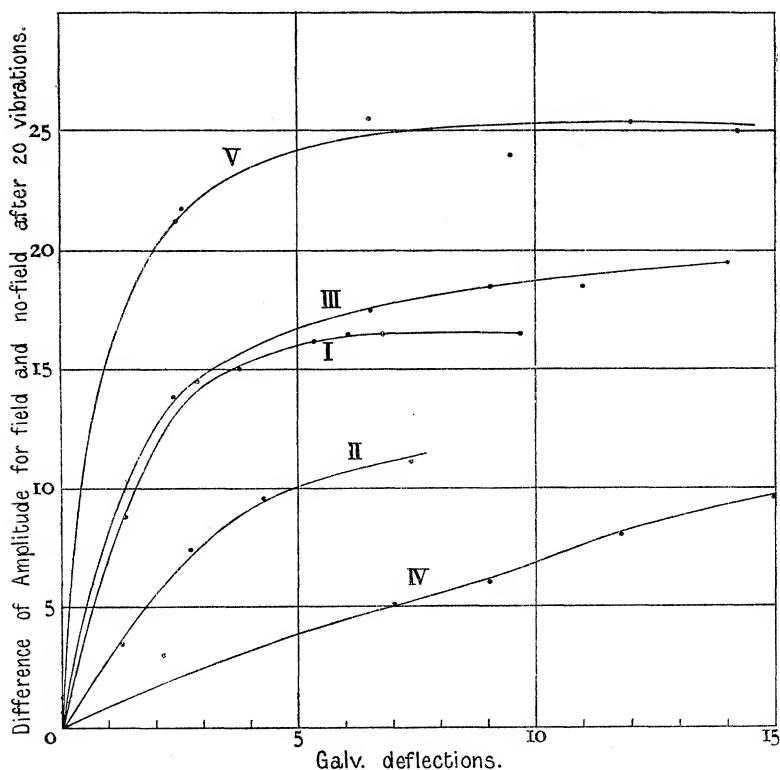
After the results shown in curve I had been obtained the wire was drawn through two holes of the draw plate, and after this treatment gave curve II. This curve is lower and rises less sharply than I, showing that the internal viscosity of the wire was not so much affected by the magnetic field as previously.

The drawn wire was then annealed, and gave curve III, which does not differ much from I. Further drawing down resulted in curve IV, which is practically a straight line, that is, the difference is now nearly proportional to the field. Re-annealing of the now much thinner wire gave curve V, which shows a very distinctly greater effect of magnetisation on viscosity than ever before. The repeated drawing and annealing process thus seems to result in the finally annealed wire in

a collocation of molecules much more easily affected by a magnetic field.

*Effect of Permanent and Temporary Strain in Nickel Wire.*—This is illustrated on fig. 3, which is constructed on the same principle as figs. 1 and 2. Curve I describes the behaviour of the wire in its original state. After this curve had been obtained for the different fields, a weight (that of a large vibrator) of 11,202 grammes was hung

FIG. 2.



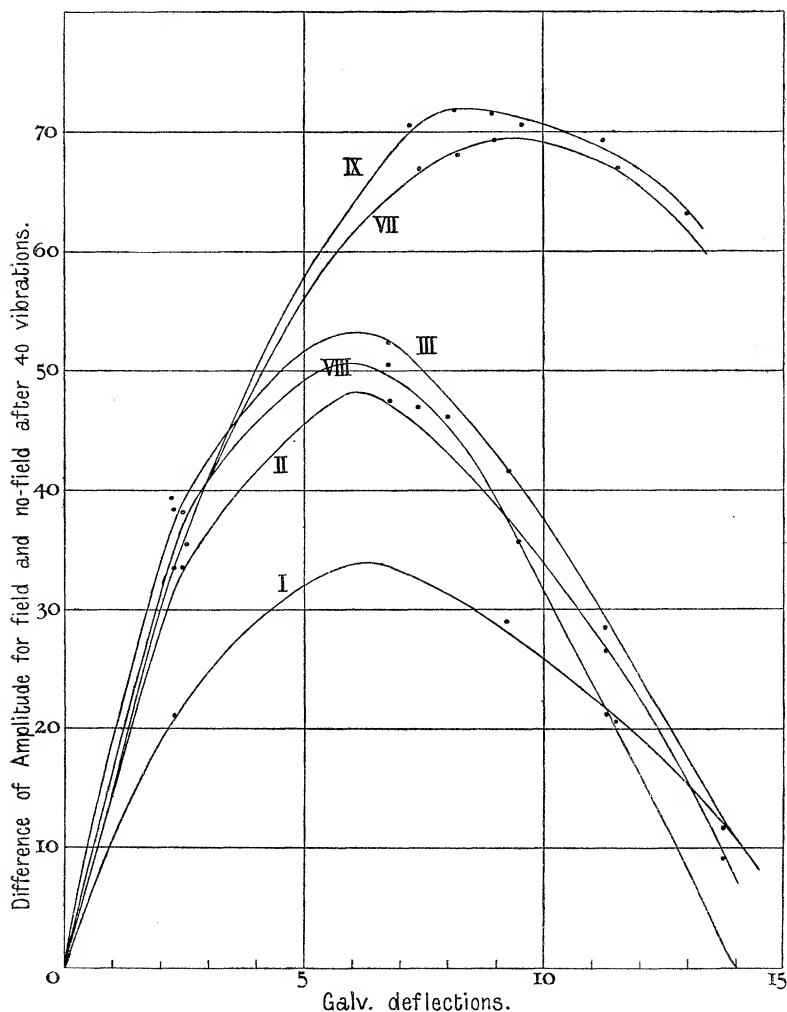
on the wire and left for two days. At the end of that time curve II was obtained, showing that the permanent strain had increased the differences of amplitude remaining after the forty oscillations. The weight was left on for another 2 days, and curve III was observed. Two repetitions of the process gave curves IV and V, which practically coincide with III, and are not drawn.

It is remarkable that permanent strain should have in nickel practically the same effect as annealing in increasing the effect of field

on the rate of subsidence, which effect it is to be remembered is in nickel an increase.\*

The wire was now allowed to rest for a few days without any weight

FIG. 3.



upon it; but it was found that the curve then obtained coincided with curves III, IV, and V, so that the rest seemed to produce no effect.

The heavy vibrator was now hung on instead of the light one, which had been used in all the previous experiments with both wires.

\* See the former paper, *loc. cit.*

Curve VII was obtained. The light vibrator and the heavy one were then used again in succession and gave curves VIII and IX. Probably the difference between curves VIII and IX was due to the additional longitudinal strain (in this case temporary) given to the wire by the additional load. The subsidences were taken for all the curves after forty vibrations no matter which vibrator was used.

The difference between curves VII and IX, it will be noticed, is a twofold one; a much greater maximum of effect and a shifting of the maximum to a greater field.

It seems not impossible that the main differences between nickel and iron disclosed by the experiments described in the previous paper, and the effects now discussed, may be explained by supposing that the groups of magnetic molecules in nickel lie in layers across the wire, separated by a matrix of conducting material which becomes hardened by drawing, and prevents the progressive changes in the groups from the initial condition of closed chains, which is brought about by magnetic force. On the other hand, the supposition would be that in iron the molecular magnets are in longitudinal groups with non-magnetic material between. Thus, in the vibrating wire in the first case, the conducting material moving in the field of the molecules would give rise to dissipation of energy, and there would be a greater rate of subsidence in the field than without it.

In the other case it is conceivable that the changes of the longitudinal and initially more or less nearly closed chains might result in such a modification of field as to result in less dissipation of energy by induction currents due to relative motion of the conducting substance and the molecular magnets, for the conducting matter between the longitudinal rows of elementary magnets may move in a feeble field after the magnetisation than before, owing to the breaking-up of the closed chains.

The effect of permanent and temporary longitudinal strain in nickel seems contrary to what we should have expected. It is known that longitudinal strain on nickel diminishes its longitudinal magnetisation, and judging from this we should have rather expected the contrary effect to that which we have observed. There is however, no doubt as to the result, which is borne out by many sets of observations. The cause must be matter for further consideration and experiment.

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